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Evaluation of an Experimental Portland Cement Concrete Pavement Project

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North Dakota DOT
Materials and Research Division
300 Airport Road
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14. Supplementary Notes

15. Abstract

Purpose and Need

Concrete pavement has been utilized in every state due to its durability. However, the pavements constructed in the last 10 to 20 years appear to be less durable than those constructed previously. The only properties normally targeted are strength and air content. These two factors alone can not guarantee durability in PCC pavement. The properties currently targeted are found using what is known as a “recipe”. There is need to change the design philosophy and look at other properties besides strength and air.

Objective

The objective is to move toward an end result specification for concrete paving by moving away from recipe mixes to a mix design philosophy with target properties.

Scope

The scope was to construct an experimental recycled portland cement concrete pavement. The experimental pavement was broken up into test sections with each having different design parameters. Individual items to be evaluated over the long term are as follows: Distresses in the pavement, overall pavement condition, ride, and long term compressive strength. The project will be evaluated for a period of ten-years with reports every two years.

The location of the project is on Interstate 29 in the southbound lane from reference point 163 to 175. This section of the roadway is located approximately 22 miles north of Grand Forks, ND.

Summary

Results of the final evaluation indicate that all sections are performing well. Minor distresses are noted in all test sections. Ride characteristics remain very good. Sections containing water reducing admixtures seem to be performing slightly better than those without admixtures.

16. Key Words

Pavement Concretes
Aggregates
Admixtures
Design
Composite

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NORTH DAKOTA
DEPARTMENT OF TRANSPORTATION

MATERIALS AND RESEARCH DIVISION

Experimental Study ND 97-02

Evaluation of an Experimental Portland Cement Concrete Pavement Project

Final Evaluation Report

Project IM-6-029(027)161

March 2011

Prepared by

NORTH DAKOTA DEPARTMENT OF TRANSPORTATION
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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1 STATE ND YEAR 1997 - NUMBER 02 SURF	CONSTRUCTION PROJ NO IM-6-029(027)161 8	LOCATION Walsh 28 Counties
	EVALUATION FUNDING 48 1 HP&R 3 DEMONSTRATION 2 X CONSTRUCTION 4 IMPLEMENTATION	NEEP NO. 49	PROPRIETARY FEATURE? Yes 51 X No

SHORT TITLE	TITLE 52 Evaluation of an Experimental Portland Cement Concrete Pavement Project

THIS FORM	DATE 28	MO. 03 --	YR. 2011	REPORTING 1 INITIAL 2 ANNUAL 3 X FINAL

KEY WORDS	KEY WORD 1 Pavement Concrete 145	KEY WORD 2 Aggregates 167
	KEY WORD 3 Admixtures 189	KEY WORD 4 Design 211
	UNIQUE WORD Composite 233	PROPRIETARY FEATURE NAME 255

CHRONOLOGY	Date Work Plan Approved: 04-97 277	Date Feature Constructed: 09-97 281	Evaluation Scheduled Until: 09-07 285	Evaluation Extended Until: 289	Date Evaluation Terminated: 05-10 293

QUANTITY AND COST	QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS) 305383 297	UNITS 1 LIN. FT 2 X SY 3 SY-IN 4 CY 5 TON 6 LBS 7 EACH 8 LUMP SUM 305	UNIT COST (*Dollars, Cents*) 7.28 306

AVAILABLE EVALUATION REPORTS	X CONSTRUCTION 315	X PERFORMANCE	X FINAL

EVALUATION	CONSTRUCTION PROBLEMS 1 NONE 2 X SLIGHT 3 MODERATE 4 SIGNIFICANT 5 SEVERE 318	PERFORMANCE 1 EXCELLENT 2 X GOOD 3 SATISFACTORY 4 MARGINAL 5 UNSATISFACTORY 319

APPLICATION	1 ADOPTED AS PRIMARY STD. 2 PERMITTED ALTERNATIVE 3 ADOPTED CONDITIONALLY 320	4 X PENDING 5 REJECTED 6 NOT CONSTRUCTED	*(Explain in remarks if 3, 4, 5, or 6 is checked)*

REMARKS	321 Results of the final evaluation indicate that all sections are performing well. Minor distresses are noted in all test sections. Ride characteristics remain very good. Sections containing water reducing admixtures seem to be performing slightly better than those without admixtures. 700

RCS HHO-30-19

Form FHWA 1461

Experimental Study ND 97- 02

Evaluation of an Experimental Portland Cement Concrete Pavement Project

FINAL EVALUATION REPORT

Project IM-6-029(027)161

March 2011

Written by

Curt Dunn, Bryon Fuchs,
Tom Bold, John Wolf, Rebecca Espinoza, and Andy Mastel

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Disclaimer

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Evaluation of an Experimental Portland Cement Concrete Pavement Project

Purpose and Need

The variables involved in concrete production continue to increase in number, while a proper examination of how these variables influence performance has not been conducted by the NDDOT. Such variables as aggregate gradation and the addition of water reducer can significantly affect the strength, durability, and overall quality of concrete pavements. An in-depth evaluation was needed to consider how current design and quality control practices may be changed or optimized.

Objective

The objective was to move towards a performance-based specification for concrete pavement by moving away from recipe mixes to a mix design philosophy with target properties. This will be done by addressing concrete quality control issues and to improve mix design procedures. The following list details specific objectives.

1) Identify a testing frequency that will be sufficient for a QC/QA specification.
2) Determine the effects of water reducing admixtures as related to performance (strength and durability), control of water/cement ratio, and cost. With this reduction in mixing water, comes a reduction in the water/cement (w/c) ratio if the amount of cementitious material is kept constant.
3) Determine the effects of dense (well) graded aggregates on strength, durability, yield, and cost.
4) Establish a formal Mix Design Procedure for concrete with admixtures.
5) Establish a relationship between compressive strength and flexural strength and determine a procedure for this relationship on an individual project basis.
6) Establish a relationship between w/c ratios calculated from the microwave oven test versus batch tickets for normal concrete and recycled concrete.
7) Determine the relationship between 28-day cylinder strength and core strength and compare the standard deviations of each.

8) Determine the uniformity of the cement and fly ash throughout the project.
9) Establish a relationship between air content (both unconsolidated and consolidated), strength, and durability.

Scope

An experimental recycled Portland Cement Concrete (PCC) pavement was designed in order to evaluate its production, construction, and long-term performance. Individual items to be evaluated during production and construction are as follows:

- Core, beam, and cylinder strengths
- Concrete durability factors
- Batch ticket information
- Impact of increased testing frequencies
- Water content by microwave method
- Cement and fly ash testing
- Concrete air content

Individual items to be evaluated over the long term are as follows:

- Distresses in the pavement
- Overall pavement condition
- Ride
- Long term compressive strength

A 1,000’ portion of each test section will be evaluated on a bi-annual basis.

Location

Project IM-6-029(027)161 was located on Interstate 29 in Walsh County from Jct ND 54 to south of Jct ND 17 in the southbound lane. The experimental pavement was divided into four test sections, each with a unique mix design. The location of the individual test sections are as follows:

Test Section 1	MP 169.5 - 175
Test Section 2	MP 164.9 - 169.5
Test Section 3*	MP 162.5 - 163.5
Test Section 4*	MP 163.5 - 164.9

* Shortage of admixture resulted in the reverse order construction of Test Sections 3 & 4.

Refer to Fig.1 on the next page for the project location.

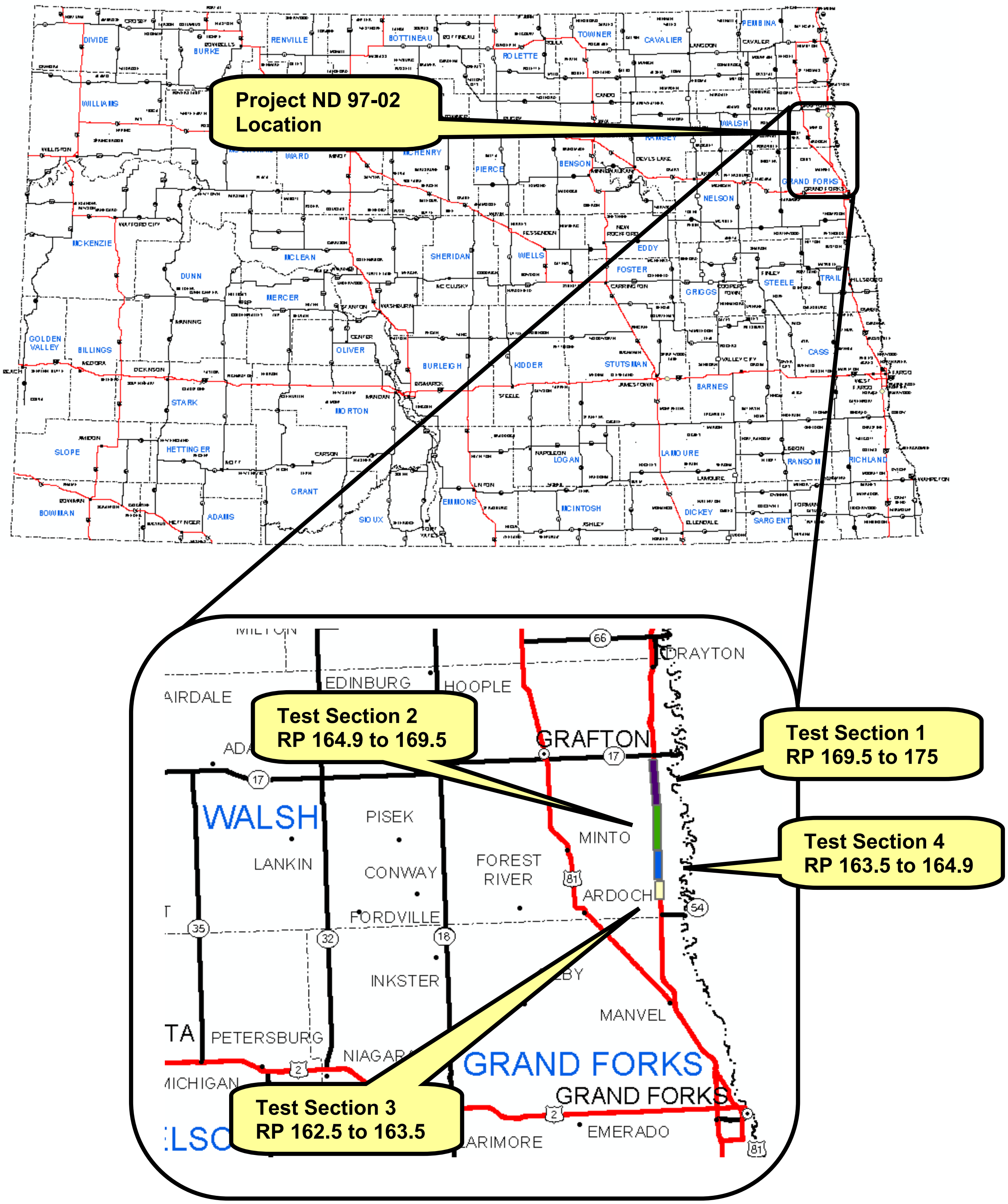

Figure 1 - Project Location.

Project Historical Information

RIMS Data

RP 161.7000	N of Jct ND 54 to Forest River					6.8959 Miles
Surface Components	**Left Shld.**	**Rdwy Width**	**Right Shld.**	**Year**	**Material**	**Depth**
Grade		48’		1971		
Lime Treated Subgrade		48’		1971		6.0”
C-C 104 Feet				1971		
Plant Mix Bit Base		41’		1972	120-150	2.0”
Cont-Reinf PCC		24’		1972		
Non-Reinf PCC	3.0’		10.0’	1972		
Comments:	Some longitudinal and transverse cracks which are spalling. Several areas where centerline tie bars are apparently missing. Transverse blowups where steel has failed.					

RP 168.6290	Forest River N to Jct 17					6.2706 Miles
Surface Components	**Left Shld.**	**Rdwy Width**	**Right Shld.**	**Year**	**Material**	**Depth**
Grade		38’		1951		
Traffic Service Gravel		22’		1951		3.9”
Selective Widening		52’		1957		
Non-Reinf PCC		24’		1957		10.0”
Joint Space 20 Foot				1957		
Aggregate Base	12.0’		12.0’	1957		8.0”
Hot Bit Pavement	10.0’		10.0’	1957	150-200	3.0”
Hot Bit Pavement	10.0’		10.0’	1972	120-150	0.8’
Concrete Pavement Repair				1987		
Contract Chip Seal	10.0’		10.0’	1989	HFMS-2	
Comments:						

Traffic

One-way traffic for the above mentioned project is shown as follows:

Year	Pass	Trucks	Total	ESALs Rigid
1998	1,700	600	2,300	865
2000	1,647	700	2,347	1,008
2004	2,050	800	2,850	1,105
2008	2,125	770	2,895	1,080

Table 1

Design

This project included 4 different mix designs, each with a different combination of water reducer and gradation type. The limits of the 4 test sections are displayed in the following table.

Experimental Section	Begin Station to End Station	Length (feet)
1	9234+70.8 - 8945+69.0	28,902
2	8945+69.0 - 8702+28.0	24,341
3	8632+90.0 - 8537+67.7	9,522
4	8702+28.0 - 8632+90.0	6,938

Table 2

The concrete pavement consisted of Portland cement, fly ash, processed salvaged concrete, virgin fine aggregate, virgin coarse aggregate, and water for all test sections as shown on the next page in Table 3. A water reducing admixture was used in Test Sections 2 and 3 as shown in Table 3. Table 3 summarizes the general characteristics of each test section:

Test Section	**1**	**2**	**3**	**4**
Cement (lb)	480	480	480	480
Fly Ash (lb)	112	112	112	112
Water/Cement Ratio (Max)	0.474	0.474	0.400	0.400
Air Content	6% ± 1%	6% ± 1%	6% ± 1%	6% ± 1%
Water Reducer	No	Yes	Yes	No
Fine & Coarse Aggregates	gap-graded	gap-graded	well-graded	well-graded

Table 3

A more detailed account of the design of project IM-6-029(027)161 is included in Special Provision 264(92) located in Appendix A.

Construction

The work for project IM-6-029(027)161 consisted of removing, crushing, screening, and stockpiling the existing PCC pavement. This recycled material was combined with new materials and used as aggregate for the new PCC pavement. The project was completed in the fall of 1997.

Construction of project IM-6-029(027)161 went well except for some delays related to workability problems in Test Section 4 and a few minor breakdowns. The paving operation was halted for an entire day because of aggregate supply problems. Approximately 1 mile of PCC pavement was produced during 1 day of paving when production was at full swing. The prime contractor was Progressive Contractors, Incorporated (PCI). The project engineer for the North Dakota Department of Transportation was Morris Evens.

Photo 1 – Concrete plant site.

The total length of the project was 13.199 miles. Upon completion of Test Section 2, the contractor's supply of water reducer became low. Test Section 3 required the use of a water reducer. Rather than halt construction, the contractor opted to place the concrete mix requirements of Test Section 4 in the original location of Test Section 3 since the concrete mix in Test Section 4 required no water reducer. NDDOT was in favor of this action.

The following photos depict some of the steps in constructing the project.

Photo 2 - Placing of the concrete

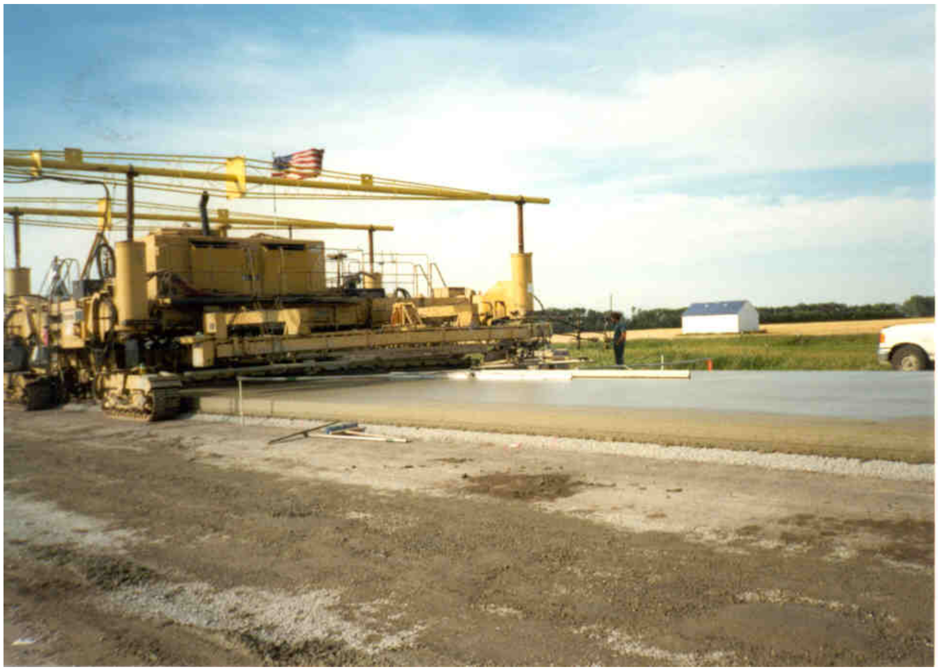

Photo 3 - Finished PCC pavement prior to carpet drag

Photo 4 - Carpet dragging finished PCC pavement

Photo 5 - Tining machine

Evaluation

During construction of project IM-6-029(027)161 much emphasis was put on the sampling and testing of the Portland Cement Concrete (PCC), as well as the individual materials needed for the PCC mix. Some of the testing frequencies normally used on PCC projects were increased for this experimental project. The data obtained from the various material tests became the basis for achieving the following objectives.

1) Identify a testing frequency that will be sufficient for a QC/QA specification.

Result: The NDDOT has decided not to go to a QC/QA specification at this time. It has been determined that the testing frequency implemented on this experimental project is more than sufficient for a QC/QA program. The current testing requirements along with the testing requirements used in this research project are shown in Appendix B.

2) Determine the effects of water reducing admixtures as related to performance (strength and durability), control of water/cement ratio, and cost.

Result: Water-reducing admixtures were used on Test Sections 2 and 3 of the experimental mix design project. The purpose was to determine what effects the admixture would have on performance as compared to the test sections where water-reducer was not added.

The special provision defined the water content of the mixture as a combination of the mixing water and free water on the surface of the aggregates, but does not include water absorbed by the aggregates.

The material included in the calculation of the w/c ratio, for the given test sections, included the water content of the batch and the total weight of the Portland cement plus the weight of the fly ash.

The special provision also required that a Type A water reducing admixture be used. The admixture was not to contain calcium chloride or interfere with the proper control of the air content of the concrete.

Mix designs for Test Sections 1 and 2 required the w/c ratio to be equal to or less than 0.47. Mix designs for Test Sections 3 and 4 required the w/c ratio to be equal to or less than 0.40.

NDDOT cast 7 and 28 day cylinders, durability beams, and flexural beams, and took 28 day cores throughout the project. The results are tabulated in Table 4 through Table 7.

Compressive Strength (PSI)								
Specimen	Test Section 1				Test Section 2			
	High	Low	Average	Standard Deviation	High	Low	Average	Standard Deviation
7 Day Cylinders	3,650	2,440	3,159	247	5,060	2,830	3,641	548
28 Day Cylinders	4,970	3,330	4,162	319	6,370	4,020	4,970	694
28 Day Cores	5,020	3,210	3,999	427	6,250	3,440	4,619	608

Table 4

Compressive Strength (PSI)								
Specimen	Test Section 3				Test Section 4			
	High	Low	Average	Standard Deviation	High	Low	Average	Standard Deviation
7 Day Cylinders	4,740	3,490	4,004	369	3,930	2,800	3,362	319
28 Day Cylinders	6,090	4,320	5,059	470	5,410	3,660	4,449	463
28 Day Cores	5,300	3,820	4,499	435	4,500	3,700	4,016	275

Table 5

PCC Beams (28 Day)	Flexural Strength (PSI)							
	Test Section 1				Test Section 2			
	High	Low	Average	Standard Deviation	High	Low	Average	Standard Deviation
	760	515	650	53	865	570	717	66

Table 6

PCC Beams (28 Day)	Flexural Strength (PSI)							
	Test Section 3				Test Section 4			
	High	Low	Average	Standard Deviation	High	Low	Average	Standard Deviation
	770	635	694	33	760	555	663	54

Table 7

Average 7 and 28 day cylinder strengths and core strengths were significantly greater for the test sections containing water reducing admixtures as shown in Tables 4 and 5.

Average 7 day cylinders increased approximately 15% from Section 1 to Section 2. Average 28 day cylinders increased approximately 19%, while average core strengths increased approximately 15% from Section 1 to Section 2.

Average 7 day cylinders increased approximately 19% from Section 4 to Section 3. Average 28 day cylinders increased approximately 13%, while average core strengths increased approximately 12% from Section 4 to Section 3.

Flexural beams showed 5 - 10% increases in the sections containing water reducing admixtures. In nearly all cases, where water reducer was used, the standard deviations were significantly greater. This is more apparent in the gap-graded mixtures.

Near the end of the completion of Test Section 2, the contractor increased the amount of water-reducer from 4 oz. to 6 oz. Comparing the test specimens involved, it was determined that when the water-reducer was increased to 6 oz. the average 7 and 28 cylinder strengths increased approximately 25%. The core strengths increased approximately 15% and the flexural beam strengths increased by approximately 11%.

In general, test sections containing water reducer had less than average w/c ratios and higher compressive and flexural strengths.

Durability tests were conducted according to ASTM C 666. Durability beams were cast and sent to the central laboratory for testing. The beams from each test section were subjected to 300 saturated freeze/thaw cycles. After the 300 cycles were completed an individual durability factor value was determined for each beam.

The purpose of these tests was to determine if certain types of concrete may be more susceptible to the development of D-cracking due to the unsoundness of the coarse aggregate. There is not established criteria for judging concrete in terms of durability factors, however, it is generally accepted the higher the durability factor value the more satisfactory the concrete is.

There were 48 durability beams tested. Because of operating difficulties, the sonometer readings on the first 17 bars were not reliable until the final readings at 300 cycles. Therefore there are not durability factors available because there are no reliable initial readings to compare to. These initial 17 beams took up all of Test Section 1 except for 3 beams. The readings for bar #38 started dropping after 36 cycles with a crack developing after 109 cycles. The relative dynamic modulus of elasticity (RDM) dropped below 60% of its initial modulus after 142 cycles. After 178 cycles the RDM was almost zero so testing on bar #38 was discontinued. Table 8 shows the durability factor (DF) values for each beam tested and their corresponding test sections.

Test Section 1		Test Section 2		Test Section 4		Test Section 3	
Beam #	DF	Beam #	DF	Beam #	DF	Beam #	DF
18	76.5	21	49.1	37	96.4	42	101.7
19	83.8	22	60.2	38	00.0	43	87.3
20	89.5	23	75.7	39	95.6	44	83.5
-----	-----	24	93.1	40	88.6	45	98.2
-----	-----	25	96.8	41	65.3	46	92.8
-----	-----	26	62.8	-----	-----	47	85.4
-----	-----	27	74.5	-----	-----	48	101.1
-----	-----	28	76.1	-----	-----	-----	-----
-----	-----	29	64.9	-----	-----	-----	-----
-----	-----	30	93.7	-----	-----	-----	-----
-----	-----	31	60.7	-----	-----	-----	-----
-----	-----	32	58.0	-----	-----	-----	-----
-----	-----	33	64.3	-----	-----	-----	-----
-----	-----	34	100.3	-----	-----	-----	-----
-----	-----	35	95.5	-----	-----	-----	-----
-----	-----	36	83.6	-----	-----	-----	-----

Table 8

One of the conclusions derived from these tests is to determine if admixtures such as water-reducers affect concrete durability.

Gap-graded Test Sections 1 and 2 had average durability factor values of 83.3 and 78.5 respectively. In this case the average DF values were higher in the section where water-reducer was not used, however, as previously mentioned, only three beams in section 1 had reliable readings. The individual DF values noted in Test Section 2 appear to vary a great deal. Some of this variability may be due to the fact that bars #26, #27, and #33 from Test Section 2, developed cracks between 200 and 280 cycles.

As previously mentioned towards the completion of Test Section 2 the water reducer was increased by 2 oz. per 100 lbs. of cementitious material. The last 3 beams in Test Section 2 were affected by the increased dosage and do exhibit higher more consistent values.

In the well-graded test sections the results were different. Where the water-reducer was utilized in Test Section 3 the average DF value was 92.9. The average DF value in Test Section 4 was 86.5. The individual values appeared to be more consistent with one another in the well-graded test sections which may indicate more uniformity in the mix. With much of the test data being unreliable in the gap-graded sections it is difficult to assess or derive any relationships between water-reducer and durability.

Two methods were used to calculate the w/c ratio: the use of a microwave oven and the traditional batch tickets. The use of the microwave oven required the inspectors to know the actual absorption of the aggregates involved. This was necessary because the microwave oven baked out all of the moisture including that which was absorbed by the aggregates.

The overall averages for Test Sections 1 and 2 are presented in Table 9. Notice in Table 9 the slight decrease in the average w/c ratio in Test Section 2 as opposed to Test Section 1. This slight decrease in the average w/c ratio would indicate the water-reducing agent allowed for slightly less mixing water to be used.

Average Water/Cement Ratios		
Method	Test Section 1	Test Section 2
Microwave	0.402	0.389
Batch	0.413	0.402

Table 9

This slight decrease, in the average w/c ratio is also present in Test Sections 3 and 4.

Average Water/Cement Ratios		
Method	Test Section 3	Test Section 4
Microwave	0.422	0.425
Batch	0.413	0.442

Table 10

Field personnel commented that the contractor had little difficulty meeting the 0.474 w/c ratio limit of Test Sections 1 and 2 even without the water reducer present in Test Section 1. The 0.400 w/c ratio limit, however, was not achievable in Test Sections 3 and 4 even with the water-reducer present in Test Section 3.

It is apparent from Table 10 that the w/c values were higher than in Table 3. It is also apparent that the w/c values in Table 10 would have met the less stringent w/c ratio limit of 0.474 used in Test Sections 1 and 2. Nevertheless, the well-graded aggregate mixtures of Test Sections 3 and 4 may require more water to achieve a desired workability. The contractor commented that NDDOT was not using the best water reducer product available. The contractor bid the project with the cheaper product and admits having better success with a costlier water reducer on other work that he had been involved in. The contractor used Polychem 400 NC water reducing admixture. At the beginning of Test Section 2, four ounces of water-reducer was used per 100 pounds of cementious material. Near the end of the test section the amount of water reducer was increased to 6 ounces.

The cost breakdown of water reducer vs increased cement is as follows.

- The unit bid price for <u>10 inch Non-Reinforced Concrete Pavement</u> was $7.28/SY. The total quantity used was 305,383 SY. The total bid price was $2,223,188.24.
- The unit bid price for <u>Portland Cement</u> was $106.00/Ton. The total quantity used was 20,359 tons. The total bid price was $2,158,054.00.
- The unit bid price for <u>Fly Ash</u> was $60.00/Ton. The total quantity used was 4,753 tons. The total bid price was $285,180.00.

- The unit bid price for Water Reducer-Type A was $4.00/Gal. The total quantity used was 3,238 gallons. The total bid price was $12,952.00.

For only $12,952.00 a substantial strength gain was obtained from using a water reducer. It is not likely that this gain could have been obtained by adding another bag of cement. At the prices listed above it would have cost $422,616 to increase the cement content from 6 to 7 bags/yd^3. Therefore, the water reducer, even though it may have been a poorer type, is still a significant bargain.

3) Determine the effects of dense (well) graded aggregates on strength, durability, yield and cost.

Result: It has been determined that a concrete containing well-graded aggregates possesses a slightly higher strength with less standard deviation than concrete containing gap-graded aggregates. Results from durability testing indicate concrete with well-graded aggregates may be slightly more durable and have higher durability values. However, workability problems still exist in the mix itself.

Tables 4 through 7 tabulate average compressive and flexural strengths of 7 and 28 day cylinders, cores, and beams along with their corresponding highs, lows, and standard deviations for all of the test sections.

Overall the test specimens cast in the well-graded test sections exhibited slightly higher strengths than that of the test sections containing gap-graded aggregates with a few exceptions.

In the well-graded section, where water reducer was not used, average 7 day cylinder strengths increased approximately 6% from that of the corresponding gap-graded section. In the well-graded section, where water reducer was used, average 7 day cylinders strengths increased approximately 10% from that of the corresponding gap-graded section.

In the well-graded section, where water reducer was not used, average 28 day cylinders strengths increased approximately 7% from that of the corresponding gap-graded section.

In the well-graded section, where water reducer was used, the average 28 day cylinders strengths increased approximately 2% from that of the corresponding gap-graded section.

Average 28 day core strengths were approximately the same in both the well-graded section and gap-graded section where water reducer was not used. In the gap-graded section, where water reducer was used, the average 28 day core strengths increased approximately 3% from that of the corresponding well-graded section.

In the well-graded section where water reducer was not used average 28 day flexural beam strengths increased approximately 2% from that of the corresponding well-graded section. In the gap-graded sections, where water reducer was used, the average 28 day flexural beam strengths increased approximately 3% from that of the corresponding well-graded section.

As previously mentioned the water reducer was increased from 4 oz to 6 oz near the end of Test Section 2. The additional 2 oz increased the strength significantly. An application rate of 6 oz was used for the duration of well-graded section 3. It is possible that some of the strength differences between sections 2 and 3 might have been diminished if Section 2 would have had the full benefit of 6 oz throughout its entirety.

Table 8 on page 16 shows the durability factor values for each beam tested, as well as their corresponding test section.

One of the conclusions to be derived from these tests is to determine if concrete utilizing well-graded aggregates will affect the durability as opposed to concrete utilizing gap-graded concretes.

The well-graded test sections exhibited higher DF values across the board with average values of 92.9 and 86.5 in Test Sections 3 and 4 respectively. The individual values appeared to be more consistent with one another in the well-graded test sections, which may indicate more uniformity in the mix. The durability factor of bars #37, #41, and #44 developed minor cracks. The durability factor of bar #41 appeared to be the only one adversely affected by the cracking.

In general, the well-graded test sections exhibited higher average DF values and more consistent individual DF values than the gap-graded sections. One reason for the increased DF values may be that the well-graded aggregate mixes were significantly finer in gradation than that of the gap-graded aggregate mixes. Recent studies have indicated that finer gradations may be less susceptible to durability cracking in concrete pavements.

While slightly better strengths and uniformity may have been attained by the use of well-graded aggregates, other items such as workability of the mix need to be improved upon. Because of the workability problems encountered in the well-graded mixes more water was added to the well-graded mix. This may have reduced the strengths. The well-graded composite gradation used in the experimental test sections may have been slightly too fine from a workability standpoint. This condition may have caused some of the workability problems during placement.

4) Establish a formal mix design procedure for concrete with admixtures.

Result: A formal mix design procedure wasn't established on this project. It became evident that mix design software would be necessary in order to establish consistent results with several variables. Further research is needed.

5) Establish a relationship between compressive strength and flexural strength and determine a procedure for this relationship on an individual project basis.

Result: Using the relationship flexural strength = a constant times the square root of compressive strength resulted in obtaining fairly consistent results. Below is a table showing a relationship of the average compressive strength for each test section to the flexural strength of each test section.

Test Section	W/C Ratio	Average 28-day Compressive Strength (psi)	Average 28-day Flexural Strength (psi)	K value(F=k(√C))
1 (gap graded w/o water reducer)	0.413	4,162	650	10.08
2 (gap graded with water reducer)	0.402	4,970	717	10.17
3 (well graded with water reducer)	0.413	5,059	694	9.76
4 (well graded w/o water reducer)	0.442	4,449	663	9.94

Table 11

With the previous relationship in mind it would be possible to establish k-values throughout the state using the different local aggregates. With k values established you could then easily determine the flexural strength from concrete cylinders on each project.

6) <u>Establish a relationship between w/c ratios calculated from the microwave oven test versus batch tickets for normal concrete and recycled concrete.</u>

Result: The conventional batch method and the microwave test method were both used to determine the water/cementitious ratio of the PCC. During the conventional batch method, the water content in the concrete mix used for the determination of the w/c ratio consisted of the water added to the mixer plus the free water carried by the aggregate. All water added to the mix was recorded by an electronic meter. The moisture contents of the aggregate (fine, virgin coarse, recycled coarse) was determined by the engineer. The batch ticket indicated the values for water added, free water, and the total water (water added plus free water).

During the microwave test method, the water content in the mix was determined from samples of the plastic concrete taken at the plant site. The water content was determined by test procedure AASHTO T 318 "Standard Test Method for Water Content Using Microwave Oven Drying." The engineer performed a water content determination each time cylinders and beams were cast and provided a summary comparison of the water content from the batch tickets and the microwave test.

Tables 12 and 13 show the results of the microwave-oven method vs. the batch method. There was no significant contradiction in water cementitious ratios between the two methods. The average w/c ratios were consistently lower using the microwave method, with the exception of Test Section 3, with the microwave method yielding approximately 97% of the batch method. The standard deviations of the results from the microwave method were smaller than those during the conventional method.

Average Water/Cement Ratios				
Method	Test Section 1		Test Section 2	
	ratio (lb/lb)	STDEV	ratio (lb/lb)	STDEV
Microwave	0.402	0.0183	0.389	0.0190
Batch	0.413	0.0213	0.402	0.0240

Table 12

Average Water/Cement Ratios				
Method	Test Section 3		Test Section 4	
	ratio (lb/lb)	STDEV	ratio (lb/lb)	STDEV
Microwave	0.422	0.0095	0.425	0.0138
Batch	0.413	0.0173	0.442	0.0174

Table 13

The results showed that the two methods were very close to one another.

7) <u>Determine the relationship between 28-day cylinder strength and core strength and compare the standard deviations of each.</u>

Result: It has been determined that no predictable, mathematical relationship exists between 28 day compressive strength data and 28 day core strength data obtained from this project.

Tables 14 and 15 show the average compressive strength values for both the 28 day cores and the 28 day cylinders. The 28 day cores consistently yielded less strength in all the test sections (approximately 88% - 96% of the cylinder strength value).

With the exception of Test Section 1, however, the standard deviations of the core strengths were less than the corresponding cylinder strengths as shown again in Tables 14 and 15. This decrease in standard deviation may indicate slightly more uniformity in the slab since the subjectivity of casting cylinders is removed.

Compressive Strength (PSI)								
Specimen	Test Section 1				Test Section 2			
	High	Low	Average	Standard Deviation	High	Low	Average	Standard Deviation
28 Day Cylinders	4,970	3,330	4,162	319	6,370	4,020	4,970	694
28 Day Cores	5,020	3,210	3,999	427	6,250	3,440	4,619	608

Table 14

Compressive Strength (PSI)								
Specimen	Test Section 3				Test Section 4			
	High	Low	Average	Standard Deviation	High	Low	Average	Standard Deviation
28 Day Cylinders	6,090	4,320	5,059	470	5,410	3,660	4,449	463
28 Day Cores	5,300	3,820	4,499	435	4,500	3,700	4,016	275

Table 15

8) Determine the uniformity of the cement and fly ash throughout the project.

Result: The type I/II cement used on the experimental project was produced by a Lafarge cement plant in Canada. The majority of the cement was obtained from Lafarge Dakota Inc. located in Valley City, North Dakota. The cement samples were taken at a frequency of approximately one per 1000 tons and submitted to the central laboratory for testing. The cement samples were tested according to AASHTO M 85. Items that the central laboratory tested are as follows:

Qualitative acid test for fly ash presence
Normal consistency
Fineness
Soundness - Autoclave expansion
Air content of mortar
Time of setting
Compressive strength

All of the cement samples submitted to the central laboratory were within the limits of AASHTO M 85. Therefore, the cement samples were uniform to the extent that the samples all met NDDOT specifications.

The fly ash used on the experimental project was Type C fly ash. It was produced by JTM Industries using fly ash produced by the Coal Creek plant near Underwood, North Dakota. The fly ash samples were taken at a frequency of approximately one per 1000 tons of fly ash and submitted to the central laboratory for testing. The fly ash samples were tested according to AASHTO M 295.

Items that the central laboratory tested are as follows.

SiO_2
$AL_2O_3+Fe_2O_3$
$SiO_2 + (AL_2O_3+Fe_2O_3)$
CaO
MgO
SO_3
Available Alkalis as Na_2O
LOI (Loss of ignition)
Moisture

All of the fly ash samples submitted to the central laboratory were within the limits of AASHTO M 295 with the following exceptions. On 4 of the 18 samples submitted the available alkalis as Na_2O was slightly higher than the 1.5% maximum requirement. The four samples in question ranged from 1.90% to 2.16%, however, this slight increase over the maximum limit should not have posed a significant problem in the quality of the concrete. One of the samples tested slightly higher for MgO. The sample in question administered 5.28% MgO and the maximum limit is 5.0%.

In conclusion, considering the minor exceptions mentioned above, the fly ash and cement samples were uniform to the extent that the samples all met NDDOT specifications.

9) Establish a relationship between air content (both unconsolidated and consolidated), strength, and durability.

Result: Comparisons were taken between 28 day cylinders, 28 day cores, 28 day flexural beams and the corresponding air percentages for all of the test sections.

During construction of the experimental project precautions were made to assure that the same concrete used for the air content testing was also used in the casting of the durability beams. Air percentages were then compared to the calculated durability factors of the beams to determine if any correlation exists between air content and durability.

During construction of the experimental project most of the samples taken have air percentages between 5.0% and 7.0%. In each test section there were percentages that fell out of the upper and lower specification range. The sampled concrete that fell out of the specified range tended to have average strengths that were less than those within the specification limits. This held true for 28 day cylinders, 28 day cores, and 28 day beams. In Test Section 2 only the sampled concrete air percentages that were within the specified limits tended to have greater durability factor values than those that fell out of the specification range. Also, in Test Section 2 the durability factor values tended to increase as the strengths increased. This held true for 28 day cylinders, 28 day cores, and 28 day beams.

In Test Sections 3 and 4 the results were mixed and no significant correlations were found. It was determined that in some of the test sections where the percent air fell out of specified range, the strength and durability values decreased slightly. This appeared to be present in the gap-graded sections, but not as apparent in the well-graded sections.

Test Section 1 (MP 169.5-175)

Test Section 1 was constructed with a concrete mix containing gap-graded aggregates without the use of water reducing admixtures.

Photo 6 - Overall view of Test Section 1.

The first evaluation of Test Section 1 on October 19, 1999 indicated corner cracking of the pavement panels at Station 8149+80, 9144+30, and 9050+00. Both the driving and passing lanes were evaluated.

The second evaluation on August 30, 2001 noted some minor distresses. The most noticeable distresses were pop-outs and low severity transverse joint spalling. There are approximately 67 transverse joints in 1,000'. The overall condition of the pavement remained very good.

The third evaluation on September 25, 2003 showed very little change in the overall condition of PCC pavement from prior evaluations. There was an increase in transverse spalling. Ride remained excellent.

The fourth evaluation on July 26, 2006 showed very little change in the overall condition of PCC pavement from prior evaluations. There was an increase in transverse joint spalling and a few minor pop-outs. The spalling at the transverse joints was minor. Ride characteristics and overall condition of the pavement was very good.

The fifth and final evaluation on November 25, 2008 revealed a few changes in the PCC pavement since the last evaluation. An area of spalling had developed at a longitudinal joint, as well as a corner break on one of the panels. Ride characteristics and overall condition remained very good. Table 16 contains a summary of the distresses for Test Section 1

Date	Evaluated Station (RP-172)	Long. Cracks	Trans. Cracks	Long. Spalling	Trans. Spalling	Corner Breaks	Other Distresses
8-30-01	9081+68 to 9071+68	0'	0'	None	19.4% of Joints	*0 Panels	Pop-outs
9-25-03		0'	0'	None	34.3% of Joints	*0 Panels	Pop-outs
7-26-06		0’	0’	None	43.3% of Joints	*0 Panels	Pop-outs
11-25-08		0’	0’	1 Joint	43.3% of Joints	*1 Panel	Pop-outs

*__Three panels were noted earlier to have corner breaks. The corner breaks were located in section 1, however, they were not located within the segment evaluated. Please note the stationing.__

Table 16

Test Section 2 (MP 164.9-169.5)

Test Section 2 was constructed with a concrete mix containing gap-graded aggregates with water reducing admixtures.

Photo 8 - Overall view of Test Section 2

The first evaluation on October 19, 1999 indicated limited distress of the pavement. The distresses present consisted of corner cracking (approximately 12" x 12" at the shoulder) and occasional aggregate pop-outs. Very little of the original tining remained in the area of Station 8930+00; however the condition of the tining improved within the section. Photo 9 provides a view of the condition of the tining at Station 8930+00.

The second evaluation on August 30, 2001 noted some minor distresses. Pop-outs continued to be the most noticeable distress in this section. Transverse joint spalling was minimal. The driving and passing lanes were evaluated. The overall condition of the pavement remained very good.

The third evaluation on September 25, 2003 showed very little change in the overall condition of PCC pavement from prior evaluations. There was an increase in transverse spalling. Ride remained excellent.

Photo 9 - Tining in Test Section 2 at Station 8930+00

The fourth evaluation on July 26, 2006 showed little change in the overall condition of PCC pavement from prior evaluations. There was an increase in transverse joint spalling and a few minor pop-outs (approximately 3” diameter or less). The spalling at the transverse joints was very minor. Ride characteristics and overall condition of the pavement remained very good.

The results of the fifth and final evaluation on November 25, 2008 were similar to prior evaluations. There was a slight increase in the number of transverse joints affected by spalling, pop-outs were minor, and the overall condition and ride of the pavement remained good. Table 17 contains a summary of the distresses for Test Section 2.

Date	Evaluated Station (RP-167)	Long. Cracks	Trans. Cracks	Long. Spalling	Trans. Spalling	Corner Breaks	Other Distresses
8-30-01	8817+37 to 8807+37	0'	0'	None	4.5% of Joints	0 Panels	Pop-outs
9-25-03		0'	0'	None	10.4% of Joints	0 Panels	Pop-outs
7-26-06		0’	0’	None	22.4% of Joints	0 Panels	Pop-outs
11-25-08		0’	0’	None	26.6% of Joints	0 Panels	Pop-outs

Table 17

Photo 10 - Typical transverse joint in Test Section 2 and pop-outs.

Test Section 3 (MP 161.9-163.5)

Test Section 3 was constructed with a concrete mix containing well-graded aggregates with water reducing admixtures.

The first evaluation of Test Section 3 on October 19, 1999 indicated very little distress. The tining in this section is very light.

The second evaluation on August 30, 2001 noted some minor distresses. The most noticeable distress observed was pop-outs. The driving and passing lanes were evaluated. The overall condition of the pavement remained very good.

The third evaluation on September 25, 2003 showed very little change in the overall condition of PCC pavement from prior evaluations except one transverse crack that crossed one 12’ lane. There was a slight increase in transverse spalling. Ride remained excellent.

The fourth evaluation on July 26, 2006 showed very little change in the overall condition of PCC pavement from prior evaluations. There was a small increase in transverse spalling and a few minor pop-outs. The spalling at the transverse joints was relatively minor. There was also a transverse crack that crossed one 12’ lane. Ride characteristics and overall condition of the pavement remained very good.

The final evaluation on November 25, 2008 revealed another slight increase in the amount of low severity transverse spalling. A transverse crack remained present across one 12’ lane. Ride characteristics and overall pavement condition continued to be good. Table 18 contains a summary of the distresses for Test Section 3

Date	Evaluated Station (RP 162-163)	Long. Cracks	Trans. Cracks	Long. Spalling	Trans. Spalling	Corner Breaks	Other Distresses
8-30-01	8590+00 to 8580+00	0'	0'	None	2.9% of Joints	0 Panels	Pop-outs
9-25-03		0’	12’	None	4.5% of Joints	0 Panels	Pop-outs
7-23-06		0’	12’	None	9.0% of Joints	0 Panels	Pop-outs
11-25-08		0’	12’	None	10.3% of Joints	0 Panels	Pop-outs

Table 18

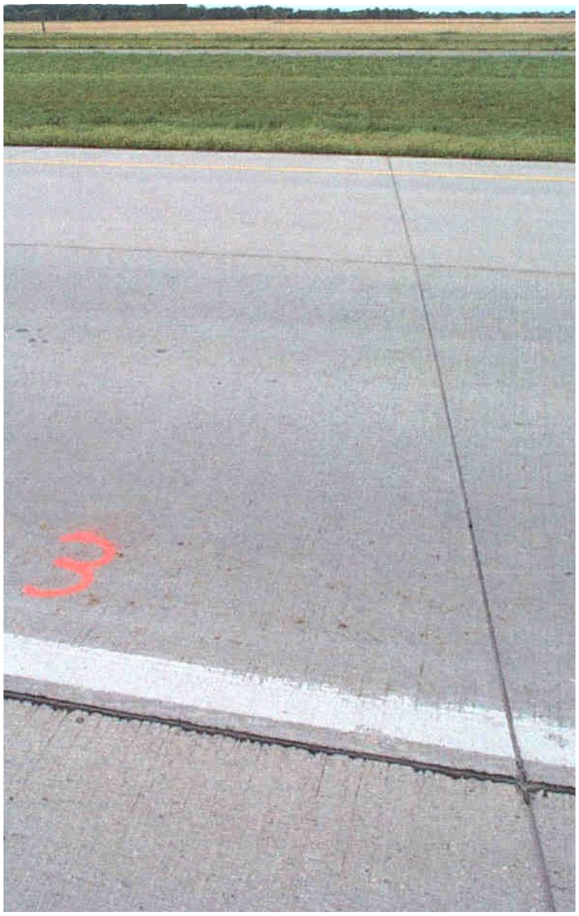

Photo 11 - Typical transverse joint and pop-outs in Test Section 3

Test Section 4 (MP163.5 -164.9)

Test Section 4 was constructed with a concrete mix containing well-graded aggregates without the use of water reducing admixtures.

Photo 12 - Overall view of Test Section 4

The first evaluation of Test Section 4 on October 19, 1999 indicated limited distress. Occasional aggregate pop-outs and low severity spalling occurred at transverse joints.

The evaluation on August 30, 2001 noted some minor distresses. The most observed distress in this test section was low severity spalling at transverse joints. Pop-outs appeared to be less frequent than in the other test sections; however, several pop-outs were significantly larger. The driving and passing lanes were evaluated.

A grind area—an area ground with a saw to ensure smoothness—exists within this test section; yet the pavement was in very good condition and the ride remained excellent.

The third evaluation on September 25, 2003 showed very little change in the overall condition of the PCC pavement from prior evaluations. There was an increase in transverse joint spalling. Ride remained excellent.

The fourth evaluation on July 26, 2006 showed very little change in the overall condition of PCC pavement from prior evaluations. There was an increase in transverse joint spalling and a few minor pop-outs (approximately 3” diameter or less). The spalling at the transverse joints was very minor. Ride characteristics and overall condition of the pavement were still very good.

The final evaluation on November 25, 2008 revealed few changes in the overall PCC pavement condition. Transverse spalling increased slightly and a longitudinal joint developed a small amount of spalling. Ride characteristics and overall condition of the pavement remained very good. Table 19 contains a summary of the distresses for Test Section 4.

Date	Station (RP-164)	Long. Cracks	Trans. Cracks	Long. Spalling	Trans. Spalling	Corner Breaks	Other Distresses
8-30-01	8659+30 to 8649+30	0'	0'	None	11.9% of Joints	0 Panels	Pop-outs
9-25-03		0’	0’	None	25.4% of Joints	0 Panels	Pop-outs
7-23-06		0’	0’	None	22.4 % of Joints	0 Panels	Pop-outs
11-25-08		0’	0’	1 Joint	32.5% of Joints	0 Panels	Pop-outs

Table 19

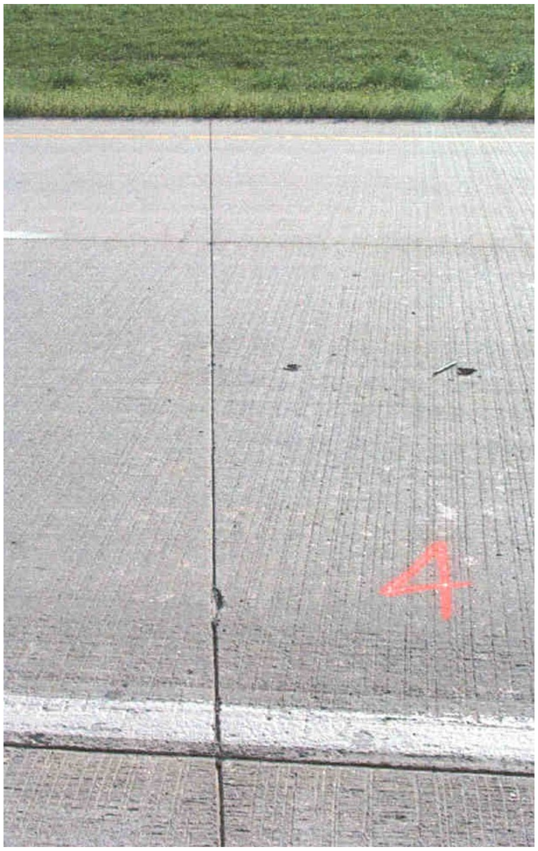

Photo 13 - Typical transverse joint spalling and a larger pop-out.

Summary

Provided below in Table 19 are the results of 28-day compressive strengths, 28-day flexural strengths, w/c ratio, and durability factor.

Test Section	**Durability Factor	W/C Ratio	Average 28-day Compressive Strength (psi)	Average 28-day Flexural Strength (psi)
1 (gap graded w/o water reducer)	83.3	0.413	4,162	650
2 (gap graded with water reducer)	75.6	0.402	4,970	717
3 (well graded with water reducer)	86.5	0.413	5,059	694
4 (well graded w/o water reducer)	92.9	0.442	4,449	663

**Some test sections had only three or four durability beams cast. Results are inconclusive.

Table 20

Test Sections 1 and 2 were exhibiting some minor corner cracking outside of the identified 1,000 foot segment used for this evaluation. All test sections were experiencing some minor aggregate pop-outs. Test Sections 2 and 3, those that utilized water reducer, were exhibiting very little distress of any type.

After the fourth evaluation, all of the test sections were performing well. The tining, although light in Test Sections 2 and 3, appeared to be performing well. The ride characteristics for all test sections remained excellent with the most notable distresses being light spalling along the transverse joints.

After the final evaluation on November 25, 2008, all test sections were still performing well. The tining, ride characteristics and overall pavement condition were still of very good quality. Table 21 provides a summary of the distresses noted during the final evaluation in each 1,000 foot segment within the test sections.

Test Section	Station	Long. Cracks	Trans. Cracks	Long. Spalling	Trans. Spalling	Corner Breaks	Other Distresses
1	9081+68 to 9071+68	0’	0’	1 Joint	43.3% of Joints	*1 Panel	Pop-outs
2	8817+37 to 8807+37	0’	0’	None	26.6% of Joints	0 Panels	Pop-outs
3	8590+00 to 8580+00	0’	12’	None	10.3% of Joints	0 Panels	Pop-outs
4	8659+30 to 8649+30	0'	0'	None	22.4% of Joints	0 Panels	Pop-outs

*Three panels were noted earlier to have corner breaks. The corner breaks were located in Section 1, however, they were not located within the segment evaluated. Please note the stationing.**

Table 21

Recommendations

It has been determined, from the analysis of the data obtained, that the use of a water reducer in the concrete mix has significantly improved the strength characteristics of the concrete. This is evident in both compressive and flexural strengths. However, water reducers tend to cause significantly greater standard deviations in the concrete's compressive and flexural strength.

- It is recommended that a water reducer be a requirement in NDDOT concrete mix designs or adopt a performance specification where the contractor is required to use a water reducer that will give adequate results.
- It is recommended that further research be conducted in optimizing mix designs containing well-graded aggregates. Results from durability and strength testing indicate concrete with well-graded aggregates may have higher durability values, as well as slightly better strength characteristics than concrete with gap-graded aggregates. Still, workability in the mix needs improvement.
- It is recommended that the NDDOT use mix design software to create a formal mix design procedure when using admixtures, as well as to optimize aggregate gradations. Trial mixes with admixtures could be batched in a laboratory atmosphere until an optimum mix design could be attained. Once an optimum mix design is attained another experimental project utilizing well-graded aggregates could then be constructed for evaluation purposes.
- It is recommended that the microwave test method be used as a verification tool on future projects, as the test results using the microwave test method and the conventional batch method are nearly identical.

Appendix A: Special Provision 264(92)

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NORTH DAKOTA DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION

RECYCLED PORTLAND CEMENT CONCRETE PAVEMENT

EXPERIMENTAL MIX DESIGN

WATER CEMENT RATIO / WATER REDUCER / WELL-GRADED AGGREGATE

IM-6-029(027)161

APRIL 18, 1997

DESCRIPTION

This work consists of removing, crushing, screening and stockpiling existing Portland Cement Concrete pavement. The recycled material will be combined with new materials to produce and place a Portland Cement Concrete pavement on a prepared surface. This project will include four test sections as follows:

Test Section	Begin Station to End Station	Length (LF)
1	8537 + 76 to 8761 + 80	22,404
2	8761 + 80 to 8902 + 55	14,075
3	8904 + 65 to 9081 + 60	17,695
4	9081 + 60 to 9234 + 72	15,312

The 10 foot shoulder and ramp tapers shall be paved using the mix design requirements for test section number one. If the Contractor paves full width, the 10 foot shoulder mix design will match the mainline paving. Sections 560 and 802 will be applied in conjunction with this Special Provision.

MATERIALS

Materials shall be as specified in Sections 550 and 802, with the following modifications:

A. **Portland Cement Concrete.** Pavement concrete shall consist of Portland Cement, fly ash, processed salvaged concrete, virgin fine aggregate, virgin coarse aggregate, water, and an air entraining admixture for all test sections as shown in Table A. A water reducing admixture shall be used in test sections 2 and 3 as shown on Table A.

B. **Mix Design.** The Department will design the concrete mixtures. Adjustments to aggregate and water content may be made to produce a mix with the required composition, workability, and consistency. Adjustments to the water content must be limited to maintain the water-cement ratio (w/c). No adjustment in Unit Price will be made because of any increase or decrease in costs which may result from adjustments in air entraining admixture dosage, water content, or aggregate proportions.

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TABLE A
MIX DESIGN PROPERTIES BY TEST SECTION

Material	1	2	3	4
Cement (Lb)	480	480	480	480
Fly Ash (Lb)	112	112	112	112
Water/Cement Ratio (Max.)	0.474	0.474	0.40	0 40
Air Content	6% ± 1%	6% ± 1%	6% ± 1%	6% ± 1%
Water Reduction	No	Yes	Yes	No
Virgin Fine Aggregate	816.01	816.01	Well-Graded	Well-Graded
Virgin Coarse Aggregate	816.02-Size 4	816.02-Size 4	Well-Graded	Well-Graded
Recycle Coarse Aggregate	816.02-Size 4	816.02-Size 4	Well-Graded	Well-Graded

1. **Strength.** The target value for compressive strength of the concrete mix will be a minimum of 5500 psi at 28 days.

2. **Cementious materials.** The minimum cement content is 564 pounds. Fly Ash will be allowed as a cement replacement and will be limited to a maximum of 20% fly ash for 15% cement by weight. The resultant weights will be 480 pounds of cement and 112 pounds of fly ash. Fly Ash will be included in the cement content by actual weight, for the determination of w/c ratio.

3. **Water Content.** The concrete mix should be designed and placed with a maximum w/c ratio equal to, or less than the maximum w/c ratio shown above. The water content includes mixing water and free water on the surface of the aggregates, but does not include water absorbed by the aggregates.

4. **Air Content.** The concrete mix shall be designed and placed with an air content of 6.0 ± 1.0 percent by volume of the freshly mixed concrete. The air content shall be continuously adjusted and maintained at 6.0 percent.

5. **Water Reducing Admixture.** A Type A water reducing concrete admixture shall be used in the concrete mix for test sections 2 and 3. The admixture shall not contain calcium chloride or interfere with the proper control of the air content of the concrete. The admixture may require adjustment of the fine material in the concrete mix. Adjustments shall be as recommended by the admixture manufacturer.

6. **Well-Graded Aggregates.** The Contractor shall provide a well-graded composite aggregate for test sections 3 and 4. The composite gradation shall be based on the combined gradation of the virgin fine, virgin coarse and recycled coarse aggregates. The fractional gradations and blend proportions necessary to produce the well-graded aggregate will be determined by the Contractor, and submitted to the Engineer prior to the development of the mix design. The composite aggregate gradations shall meet the following gradation limits:

Composite Gradation Limits

Sieve Size	Percent Passing
1"	100
3/4"	90 - 100
1/2"	80 - 90
3/8"	75 - 85
No. 4	60 - 70
No. 8	45 - 55
No. 16	30 - 40
No. 30	15 - 25
No. 50	5 - 15
No. 100	0 - 10
No. 200	0 - 4

All aggregates shall be blended at the batch plant. The combined gradation may be determined by mathematical computations. The Contractor may submit alternate well-graded composite gradation limits for review and approval by the Engineer.

a. **Virgin Fine Aggregates.** Fine Aggregate is defined as that portion of aggregate that passes the No. 4 sieve. A maximum of 5% of the material may be retained on the No. 4 sieve. Fine aggregates shall meet Section 816.01 A.2.

b. **Virgin Coarse Aggregates.** Coarse Aggregate is defined as that portion of aggregate retained on the No. 4 sieve. A minimum of 95% of the of the material shall be retained on the No. 4 sieve. Virgin coarse aggregate shall meet Section 816.02 A.2.

c. **Recycled Coarse Aggregate.** Coarse Aggregate is defined as that portion of aggregate retained on the No. 8 sieve. Recycled coarse aggregate shall have a maximum aggregate size of 1 inch. Salvaged material passing the No. 8 sieve shall be limited to less than 5 percent. Salvaged fines shall not be used in the new concrete. Recycled coarse aggregate shall be limited to 80 percent of the total coarse aggregate (virgin coarse aggregate plus recycled coarse aggregate). The ratio of virgin coarse to recycle coarse aggregate shall be the same for all test sections.

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C. **Submittals.** A minimum of 14 days prior to the beginning of paving operations, the Contractor shall submit the following to the Engineer for review and approval:

1. **Source and Certification.** The sources and certifications for all materials in the concrete mixtures.

1. **Well-Graded Aggregate.** The aggregate gradations, proportions, and sources for all materials in the well-graded aggregate.

2. **Air Entraining Admixture.** The type and brand of air entraining admixture and the Manufacturer's recommended usage of the air entraining admixture.

3. **Water Reducing Admixture.** The type and brand of water reducer admixture and the Manufacturer's recommended usage of the water reducing admixture.

4. **Trial Mix Design.** The Contractor shall provide representative samples of all materials in the concrete mixture for trial mix designs. A sample tag identifying the project number and material shall be attached to the samples. The minimum size samples for the trial mix design are as follows:

Material	**Sample**
Cement	225 lb.
Fly Ash	50 lb.
Fine Aggregate	500 lb.
Coarse Aggregate	800 lb.
Air Entraining Admixture	1 gal.
Water Reducing Admixture	1 gal.

The sample sizes may require adjustment due to actual conditions and operations.

If aggregates, cement, fly ash, water or other admixtures are utilized from sources other than those initially submitted the Contractor shall notify the Engineer five days before incorporating the material into the work.

CONSTRUCTION REQUIREMENTS

The Project will be constructed according to Section 560 with the following modifications:

B. **Stockpiling.** Delete the second paragraph of Section 560.04 B in its entirety.

E. **Processing Salvaged Concrete.** Add the following after the second pargraph of Section 560.04 E.

Salvaged fines shall not be used in the new concrete.

The salvaged concrete for the well-graded aggregate shall be crushed to such a gradation that when combined with the virgin aggregates it will meet the specified gradation.

F. **Mixing.** Add the following to Section 560.04 F.

1. **Water-Cement (W/C) Ratio.** The determination of the w/c ratio will be based on the following procedures:

   a. **Water Content.** The water content in the concrete mix used for the determination of the w/c ratio shall consist of the water added to the mixer plus the free water carried by the aggregate.

      All water added to the mix shall be recorded by an electronic meter. The moisture contents of the aggregate (fine, virgin coarse, recycled coarse) shall be determined by the Engineer. The batch ticket shall indicate the values for water added, free water, and the total water (water added plus free water).

      For informational purposes, the water content in the mix shall also be determined from samples of the plastic concrete taken at the plant site. The water content will be determined by test procedure: AASHTO TP23-93 "Standard Test Method for Water Content Using Microwave Oven Drying." The Engineer will perform a water content determination each time cylinders and beams are cast and should provide a summary comparison of the water content from the batch tickets and the microwave test.

   b. **Cement Content.** The cement content shall be determined from the batch ticket weight.

      The cement content will be verified by cement cut-offs and recalibration of the cement scales. The Contractor shall perform a minimum of 2 cement cut-offs and recalibrate the cement scales for each three miles of paving, mainline and shoulders.

   c. **Cement Tolerance.** The cement content shall be maintained within a tolerance of ± 1%. The cement content may require adjustments as follows:

      1. If concrete having the required consistency cannot be produced without exceeding the maximum allowable w/c ratio, the cement content shall be increased so the maximum w/c ratio is not exceeded.

      2. If the concrete produced in the field does not meet the strength requirements, the cement content shall be increased until the strength requirements are met.

      The Contractor will be reimbursed for additional cementious materials necessary to meet the requirements of this Special Provision.

   d. **Water-Cement (W/C) Ratio.** The w/c ratio will be determined by dividing the batch ticket weight of the total water by the combined batch ticket weights of cement and fly ash.

METHOD CF MEASUREMENT

The Method of Measurement will be according to Section 560.05 with the following modifications:

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Delete the second paragraph of Section 560.05 A in its entirety and replace with the following:

> All virgin P.C.C. pavement aggregate, salvaged concrete, and salvaged bituminous stockpiled at the plant site shall be considered the property of the Contractor. Payment will not be made for salvaged material which is stockpiled and not incorporated into the project.

Add the following to Section 560.06:

G. **Water Reducer - Type A.** This item will be measured by the Gallon. The volume of water reducer will be determined from the actual batch weight used (ounces) minus any waste. The batch weight will be converted to gallons be dividing the batch weight by 128 ounces per gallon.

BASIS OF PAYMENT

The Basis of Payment will be according to Section 560.05 with the following modifications:

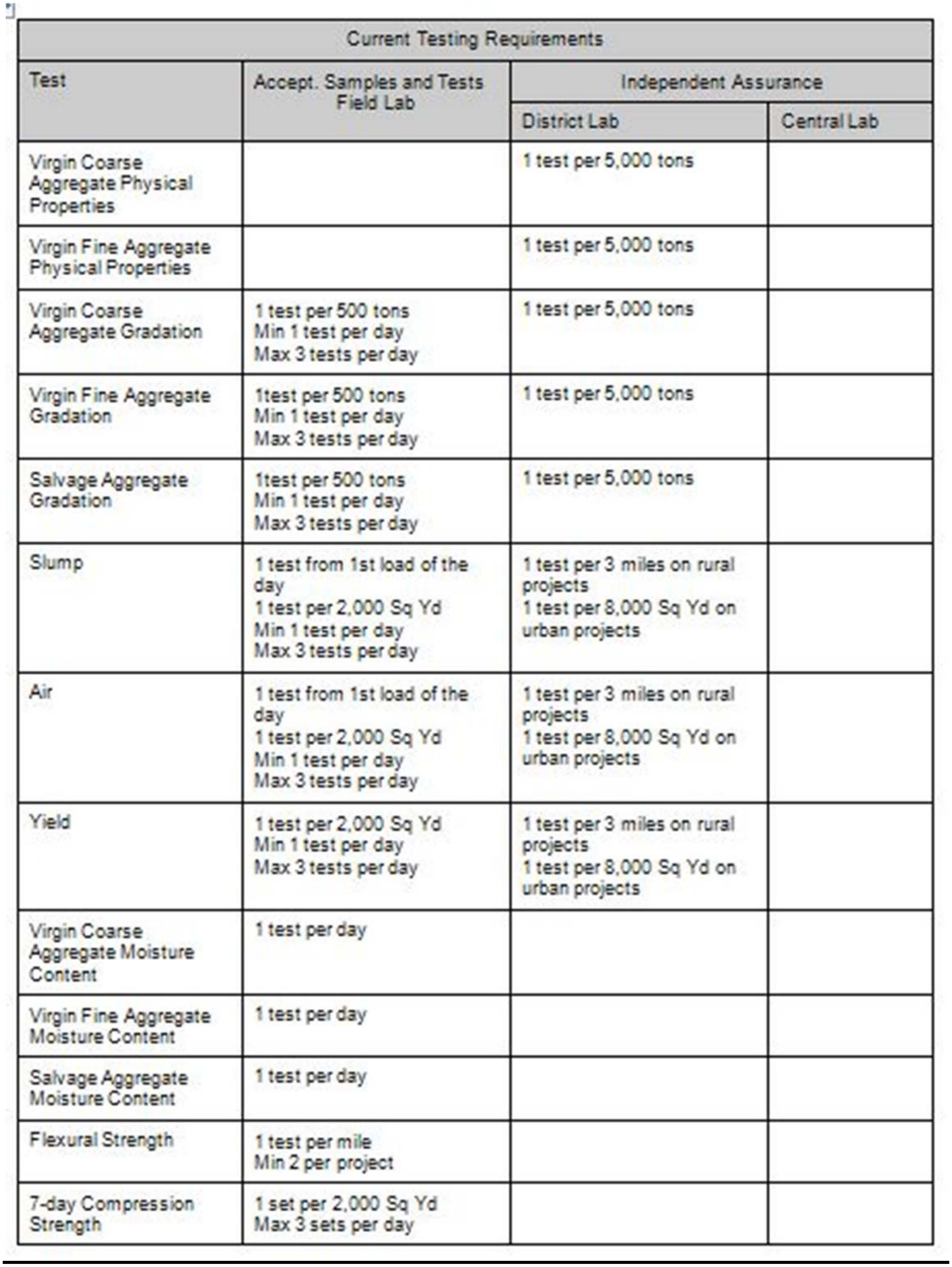
Remove the last paragraph of Section 560.06 A and replace with the following:

> Water, Air-Entraining Admixture, Virgin Fine Aggregate , Virgin Coarse Aggregate, and Recycle Coarse Aggregates (including the processing of recycled concrete pavement), will not be measured for payment but will be included in the price bid for "Nonreinforced Recycled Concrete Pavement ."

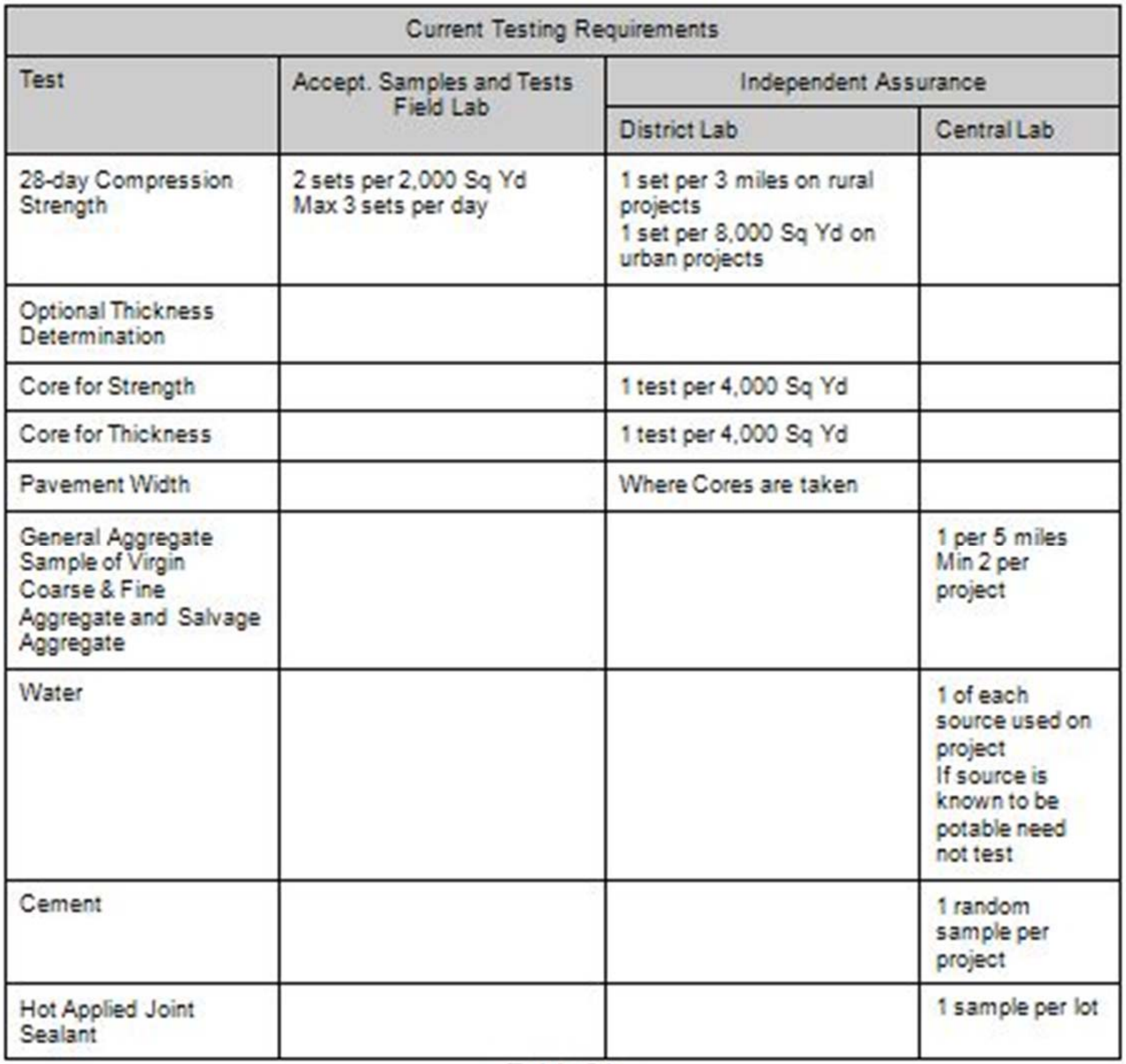
Add the following pay item to Section 560.06 A:

Pay Item	Pay Unit
Water Reducer - Type A	Gallon

Appendix B: QC/QA Data



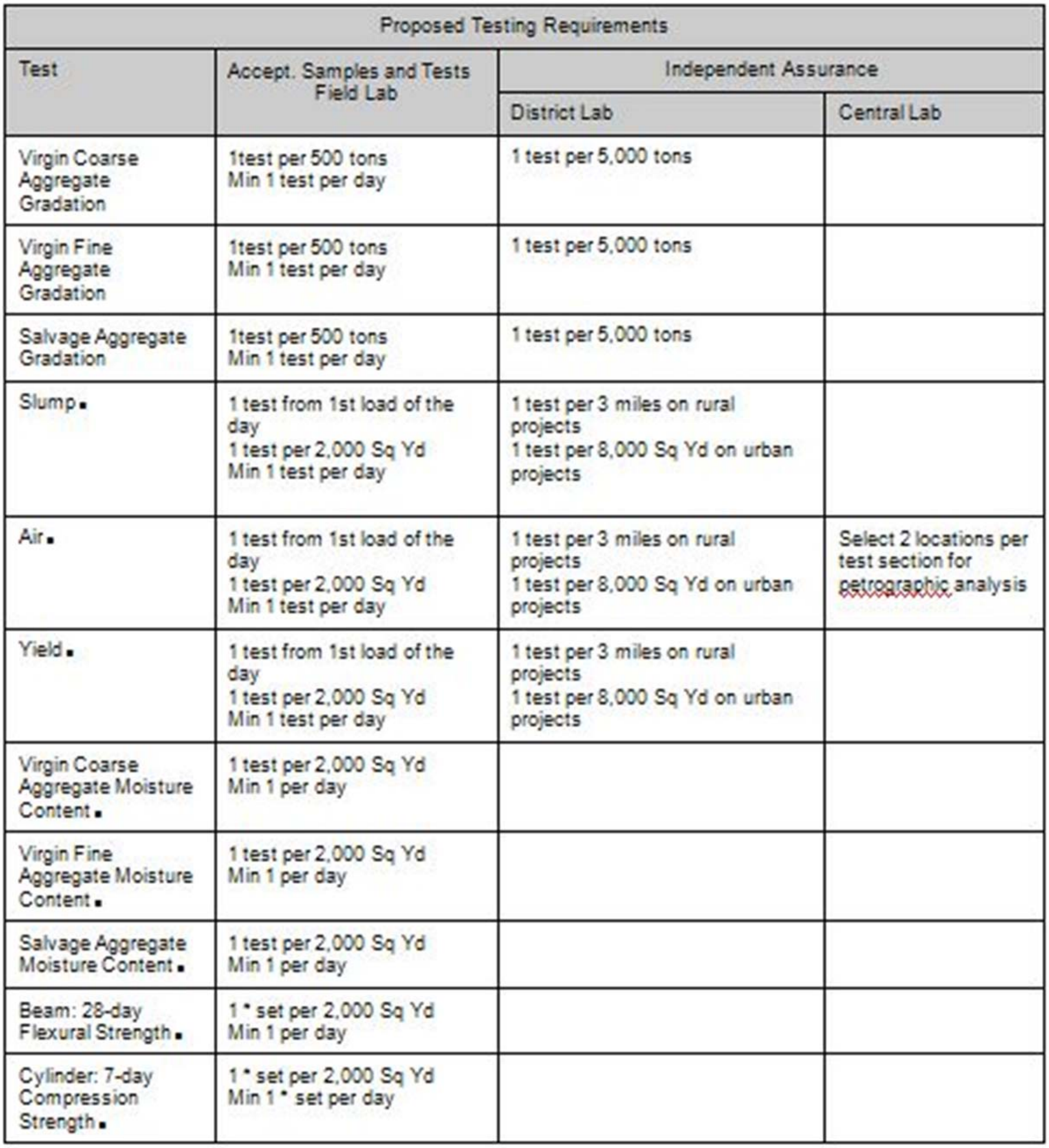
Current Testing Requirements			
Test	Accept. Samples and Tests Field Lab	Independent Assurance	
		District Lab	Central Lab
Virgin Coarse Aggregate Physical Properties		1 test per 5,000 tons	
Virgin Fine Aggregate Physical Properties		1 test per 5,000 tons	
Virgin Coarse Aggregate Gradation	1 test per 500 tons Min 1 test per day Max 3 tests per day	1 test per 5,000 tons	
Virgin Fine Aggregate Gradation	1test per 500 tons Min 1 test per day Max 3 tests per day	1 test per 5,000 tons	
Salvage Aggregate Gradation	1test per 500 tons Min 1 test per day Max 3 tests per day	1 test per 5,000 tons	
Slump	1 test from 1st load of the day 1 test per 2,000 Sq Yd Min 1 test per day Max 3 tests per day	1 test per 3 miles on rural projects 1 test per 8,000 Sq Yd on urban projects	
Air	1 test from 1st load of the day 1 test per 2,000 Sq Yd Min 1 test per day Max 3 tests per day	1 test per 3 miles on rural projects 1 test per 8,000 Sq Yd on urban projects	
Yield	1 test per 2,000 Sq Yd Min 1 test per day Max 3 tests per day	1 test per 3 miles on rural projects 1 test per 8,000 Sq Yd on urban projects	
Virgin Coarse Aggregate Moisture Content	1 test per day		
Virgin Fine Aggregate Moisture Content	1 test per day		
Salvage Aggregate Moisture Content	1 test per day		
Flexural Strength	1 test per mile Min 2 per project		
7-day Compression Strength	1 set per 2,000 Sq Yd Max 3 sets per day		



Current Testing Requirements

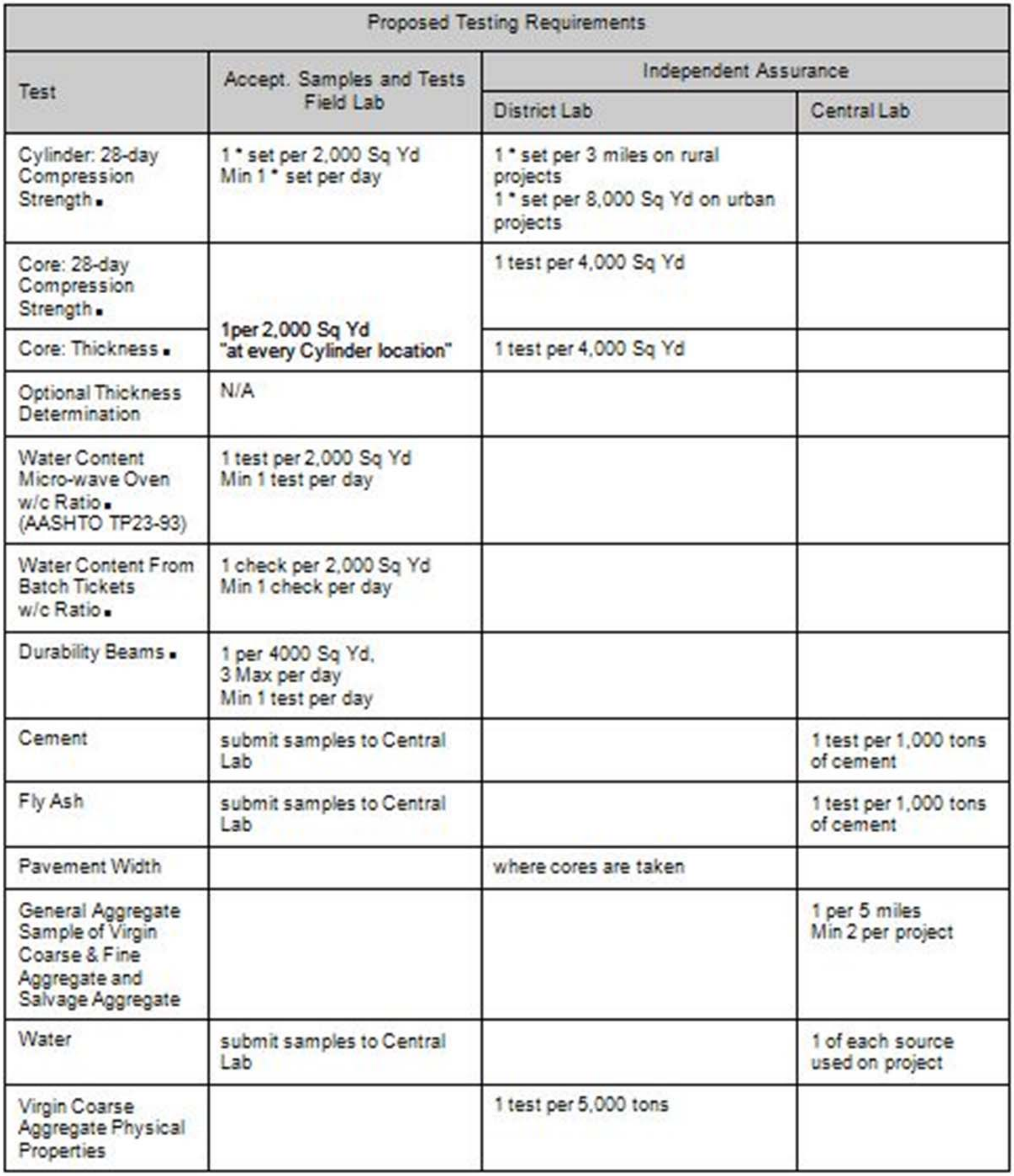
Test	Accept. Samples and Tests Field Lab	Independent Assurance	
		District Lab	Central Lab
28-day Compression Strength	2 sets per 2,000 Sq Yd Max 3 sets per day	1 set per 3 miles on rural projects 1 set per 8,000 Sq Yd on urban projects	
Optional Thickness Determination			
Core for Strength		1 test per 4,000 Sq Yd	
Core for Thickness		1 test per 4,000 Sq Yd	
Pavement Width		Where Cores are taken	
General Aggregate Sample of Virgin Coarse & Fine Aggregate and Salvage Aggregate			1 per 5 miles Min 2 per project
Water			1 of each source used on project If source is known to be potable need not test
Cement			1 random sample per project
Hot Applied Joint Sealant			1 sample per lot

Table 21



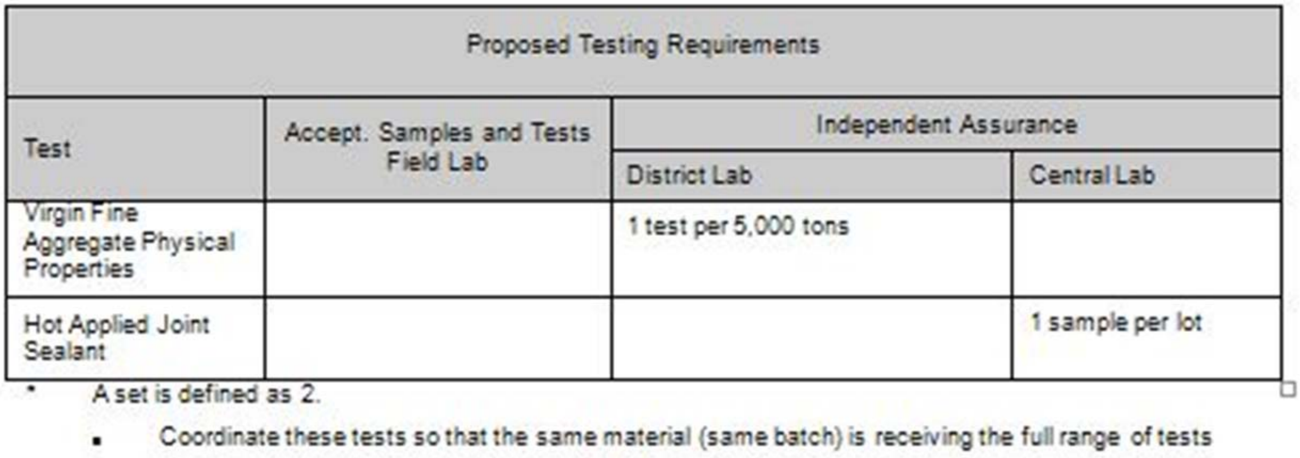
Proposed Testing Requirements

Test	Accept. Samples and Tests Field Lab	Independent Assurance	
		District Lab	Central Lab
Virgin Coarse Aggregate Gradation	1test per 500 tons Min 1 test per day	1 test per 5,000 tons	
Virgin Fine Aggregate Gradation	1test per 500 tons Min 1 test per day	1 test per 5,000 tons	
Salvage Aggregate Gradation	1test per 500 tons Min 1 test per day	1 test per 5,000 tons	
Slump ▪	1 test from 1st load of the day 1 test per 2,000 Sq Yd Min 1 test per day	1 test per 3 miles on rural projects 1 test per 8,000 Sq Yd on urban projects	
Air ▪	1 test from 1st load of the day 1 test per 2,000 Sq Yd Min 1 test per day	1 test per 3 miles on rural projects 1 test per 8,000 Sq Yd on urban projects	Select 2 locations per test section for petrographic analysis
Yield ▪	1 test from 1st load of the day 1 test per 2,000 Sq Yd Min 1 test per day	1 test per 3 miles on rural projects 1 test per 8,000 Sq Yd on urban projects	
Virgin Coarse Aggregate Moisture Content ▪	1 test per 2,000 Sq Yd Min 1 per day		
Virgin Fine Aggregate Moisture Content ▪	1 test per 2,000 Sq Yd Min 1 per day		
Salvage Aggregate Moisture Content ▪	1 test per 2,000 Sq Yd Min 1 per day		
Beam: 28-day Flexural Strength ▪	1 * set per 2,000 Sq Yd Min 1 per day		
Cylinder: 7-day Compression Strength ▪	1 * set per 2,000 Sq Yd Min 1 * set per day		



Proposed Testing Requirements

Test	Accept. Samples and Tests Field Lab	Independent Assurance	
		District Lab	Central Lab
Cylinder: 28-day Compression Strength ■	1 * set per 2,000 Sq Yd Min 1 * set per day	1 * set per 3 miles on rural projects 1 * set per 8,000 Sq Yd on urban projects	
Core: 28-day Compression Strength ■	**1per 2,000 Sq Yd "at every Cylinder location"**	1 test per 4,000 Sq Yd	
Core: Thickness ■		1 test per 4,000 Sq Yd	
Optional Thickness Determination	N/A		
Water Content Micro-wave Oven w/c Ratio ■ (AASHTO TP23-93)	1 test per 2,000 Sq Yd Min 1 test per day		
Water Content From Batch Tickets w/c Ratio ■	1 check per 2,000 Sq Yd Min 1 check per day		
Durability Beams ■	1 per 4000 Sq Yd, 3 Max per day Min 1 test per day		
Cement	submit samples to Central Lab		1 test per 1,000 tons of cement
Fly Ash	submit samples to Central Lab		1 test per 1,000 tons of cement
Pavement Width		where cores are taken	
General Aggregate Sample of Virgin Coarse & Fine Aggregate and Salvage Aggregate			1 per 5 miles Min 2 per project
Water	submit samples to Central Lab		1 of each source used on project
Virgin Coarse Aggregate Physical Properties		1 test per 5,000 tons	



Proposed Testing Requirements			
Test	Accept. Samples and Tests Field Lab	Independent Assurance	
		District Lab	Central Lab
Virgin Fine Aggregate Physical Properties		1 test per 5,000 tons	
Hot Applied Joint Sealant			1 sample per lot

* A set is defined as 2.

- Coordinate these tests so that the same material (same batch) is receiving the full range of tests

Table 22

Table 21 contains NDDOT's current testing requirements normally used on PCCP projects and Table 22 contains the adjusted testing requirements recently used on the experimental project.

Several of the testing frequencies remained unchanged, however, the frequency of tests such as aggregate moisture contents and casting of flexural beams were increased to two tests every 2000 square yards with at least one test per day. Cement samples were also increased in frequency from one sample per project to one sample per 1,000 tons of cement. Additional testing included two different methods for testing water content of the mix and taking fly ash samples.

In order to achieve these frequencies, field personnel performed the testing every 642 linear feet (2000 square yards) of pavement. The concrete paving rate was approximately 400 to 425 linear feet per hour which amounted to concrete testing every 1.5 hours. Field personnel commented, that when production was consistent, the testing frequencies were somewhat overdone based on the consistent, predictable results that the contractor achieved.

Plant inspection personnel had no problem keeping up with sampling aggregates, concrete, fly ash, and cement although the lab and road testing personnel had to be extremely organized to keep ahead with the actual test work.

Plant inspection personnel commented that the contractor should be required to obtain all of the aggregate samples for two reasons: safety issues, and also to remove any concerns the contractor may have as to whether or not a representative sample was obtained.